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DIVISION SIX-SECTION 6.1

WATER TUNNEL TESTS OF THE

4.5" ROCKET PROJECTILE

THE HIGH SPEED WATER TUNNEL

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA.

ND 12

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MEMORANDUM ON WATER TUNNEL TESTS OF A 4.5" ROCKET PROJECTILE

(Laboratory Designation ND-12)

BY

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THE HIGH SPEED WATER TUNNEL
AT THE
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Section No
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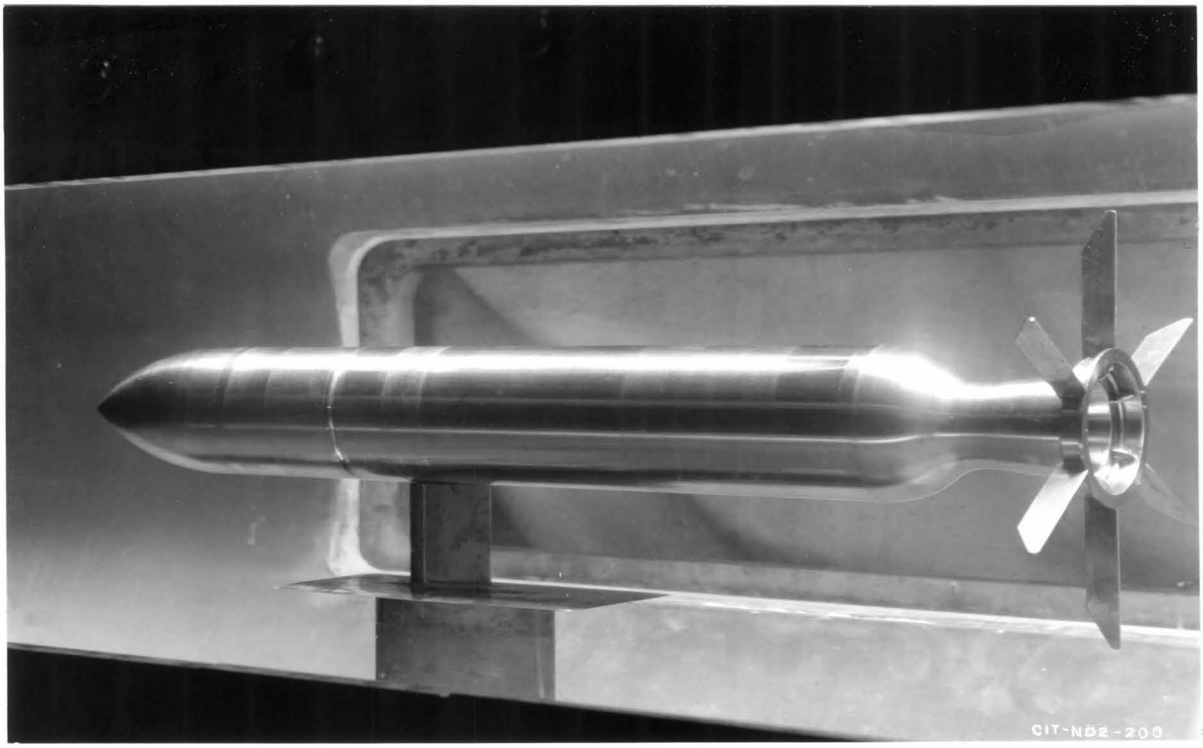


FIGURE 1
4.5" ROCKET PROJECTILE SHOWN MOUNTED
IN THE WATER TUNNEL WORKING SECTION

MEMORANDUM ON WATER TUNNEL TESTS OF A 4.5" ROCKET PROJECTILE

(Laboratory Designation, ND-12)

1. TYPE OF PROJECTILE AND PURPOSE OF TESTS.

This report covers water tunnel tests of a 2" diameter model of a 4.5" rocket projectile (designated in the laboratory as projectile number ND-12) with a fin tail and with the tail replaced by a spinner tube. The purpose of the tests was to determine the magnitude of the hydrodynamic forces acting on the body as functions of its orientation with respect to the direction of motion, and to determine the location of the point of application of those forces.

2. TUNNEL INSTALLATION AND DESCRIPTION OF FORCES MEASURED.

The tests were conducted in the 14" diameter working section of the High Speed Water Tunnel at the California Institute of Technology.(1) Figure 1 shows the projectile installed in the tunnel. In order to reduce the drag tare to a minimum, the rigid supporting spindle is protected from the flow by the streamline shielding shown in the figure. This shielding which projects to within a few thousandths of an inch of the projectile is held to a small size in order to reduce interference effects.

The forces exerted by the flow on the model can be resolved, in general, into a drag force parallel to the flow, a cross wind normal to the flow, and moment or torque acting about the point of support. These are the forces measured during the tests. The moment exists only if the model is not supported at the point of application of the resultant of all the hydrodynamic forces. It is clear that the magnitude and sense of the measured moment will change if the point of support is shifted along the body.

The Water Tunnel tests give results which are applicable in either air or water for velocities below that of sound. For velocities in the neighborhood or above that of sound the results will not apply. The data presented in this report have not been corrected for scale effect, tare or interference of the model support. However, they are believed to be reliable since they agree closely with data obtained from full scale projectiles in free flight.

3. REPRESENTATION OF TEST DATA.

The hydrodynamic characteristics are presented in the form of curves of force coefficients as functions of the angle of yaw. In addition, the distance of the center of pressure from the nose of the projectile expressed as a fraction of the length of the projectile is plotted against yaw angle. The center of pressure is defined as the point at which the resultant hydrodynamic force vector intersects the axis of symmetry of the model.

(1) **Figures refer to references listed at the end of this report.**

The force coefficients, C_D, for drag and, C_C, for cross wind force are expressed as:

$$C_D = \frac{D}{\rho \frac{V^2}{2} A_D}$$

and

$$C_C = \frac{C}{\rho \frac{V^2}{2} A_D}$$

where

D = measured drag force in lbs

C = measured cross wind force in lbs

ρ = density of water in slugs per cu ft

A_D= area in sq ft of a cross section at the cylindrical portion of the projectile taken normal to the geometric axis of the projectile

V = mean relative velocity between the water and the projectile in ft per sec

The moment coefficient is expressed as:

$$C_M = \frac{M}{\rho \frac{V^2}{2} A_D \; L}$$

where

M = moment in in-lbs measured about any particular point on the geometric axis of the projectile

L = overall length of the projectile in in. (For all combinations of the model projectile discussed in this report L is taken as .489".)

The distance from the nose of the center of pressure (center of pressure distance) as a fraction of the overall projectile length is expressed as:

$$\frac{\bar{x}}{L} = \frac{L' + L''}{L} = \frac{L'}{L} + \frac{1}{L} \frac{M}{(C \cos \psi + D \sin \psi)}$$

L'= distance in in from the projectile nose to the center of moments

L''= distance in in from the center-of-pressure to the center of moments

ψ = yaw angle in degrees

When M is the measured moment the center of moments is at the support point of the model and L" then is the distance from the support point to the center-of-pressure. The signs of the moment, M, the cross wind force, C, and the yaw angle, ψ, are such that a positive or clockwise moment will tend to increase a positive or clockwise yaw angle, while the corresponding positive cross wind force will act in the same direction as the displacement of the projectile nose for a positive yaw.

The curves of force and moment coefficients and of center-of-pressure distance plotted as functions of the yaw angle are useful for a discussion of the stability of projectiles. Since these tunnel tests are made under steady flow conditions the results will only indicate the tendency of the projectile to return to or move away from the equilibrium position after a disturbance. Adopting aerodynamic usage a projectile is said to be "statically" stable if it tends to return to equilibrium when disturbed. In the discussion of static stability the actual motion following the perturbation is not considered at all. In fact, a projectile may oscillate about the equilibrium position without ever remaining in it. In this case the projectile would be statically stable even though "dynamically" stable. For a complete discussion of the mode of motion to be expected following a perturbation, the "dynamic" stability, additional information is necessary.

The condition for equilibrium is satisfied if C_M calculated about the C.G. is equal to zero. In general, for projectiles with axial symmetry the moment is zero at $\psi = 0^o$ so that for equilibrium the projectile is oriented with its axis parallel to the direction of motion. If the projectile is rotated from the equilibrium position so as to give it a positive yaw angle it is necessary that it have a negative moment coefficient, according to the sign convention adopted, in order that it be statically stable. Thus a negative slope of the curve C_M vs. ψ corresponds to static stability, and a positive slope corresponds to instability. The degree of stability or instability is measured by the magnitude of the slope. The same conclusions are obtained by interpreting the center-of-pressure curves. For symmetrical projectiles, if the center of pressure falls behind the center of gravity a negative or restoring moment exists and the projectile is statically stable. If the C.P. lies ahead of the C.G. the moment is nonrestoring and the projectile is statically unstable. The degree of stability or instability is measured by the distance between the center of gravity and center of pressure.

4. DESCRIPTION OF PROJECTILE.

The 4.5" rocket projectile is composed of a cylindrical body, an ogive nose, an afterbody formed by the motor nozzle, and a collapsible tail. The radius of curvature of the ogive nose is 1.78 calibers. The collapsible tail is made up of six fins mounted on the rim of the motor nozzle. Figures 2, 3, and 4 show the projectile model with the fins in the unfolded position assumed during flight. Figure 12 is a cross section assembly drawing of the model. Construction details of the tail are shown by the drawing in Figure 13 and by the photographs in Figures 5 and 6.

The rocket was also tested with the tail replaced by a device designed to cause it to spin during flight. This device is called the Spinner Tube, Model I. The details of the construction as adapted for the model are shown by the drawing in Figure 14 and by the photographs in Figures 10 and 11. The fins have been removed and a cylindrical extension added to the model nozzle. This cylinder, whose inside diameter is equal to the maximum diameter of the nozzle, has four longitudinal side port openings with four vanes which are tangent to the cylindrical surface. The ports are so located that a portion of the gases issuing from the motor nozzle will pass through them and by acting against the vanes, cause the projectile to rotate about its geometric axis. For the prototype, the fins would be skewed with respect to the axis of the projectile so that as the rocket spins in flight the relative angle of attack between the air and the fins would be zero. For the model construction, the ports and the vanes are parallel to the geometric axis. This is necessary since tunnel tests must be made without spin. The projectile is shown assembled with the spinner tube in Figures 7, 8, and 9.

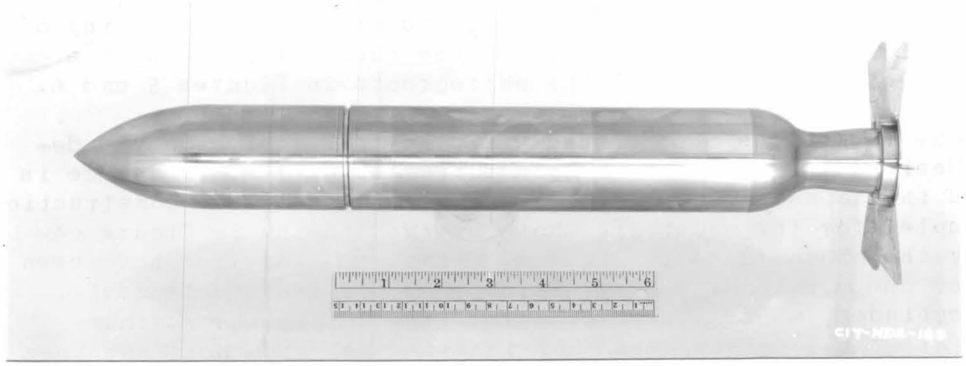


FIGURE 2

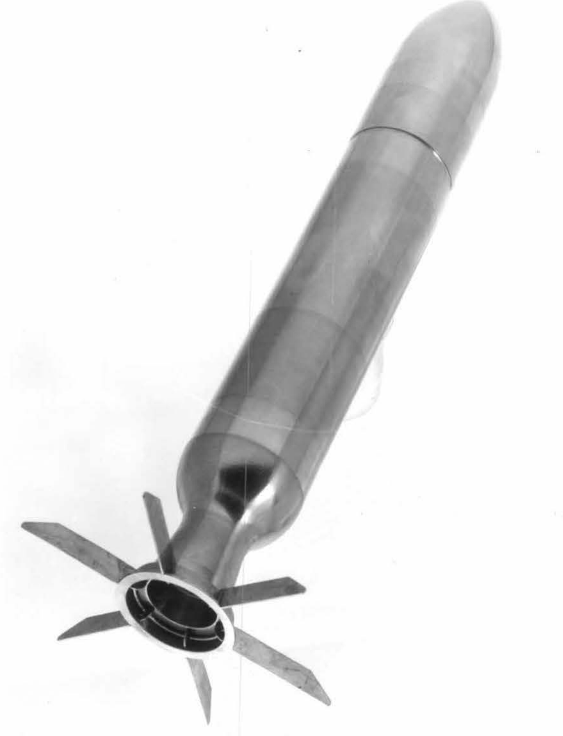


FIGURE 3

FIGURE 4

VIEWS OF 4.5" ROCKET PROJECTILE WITH
FINS IN UNFOLDED POSITION ASSUMED DURING FLIGHT

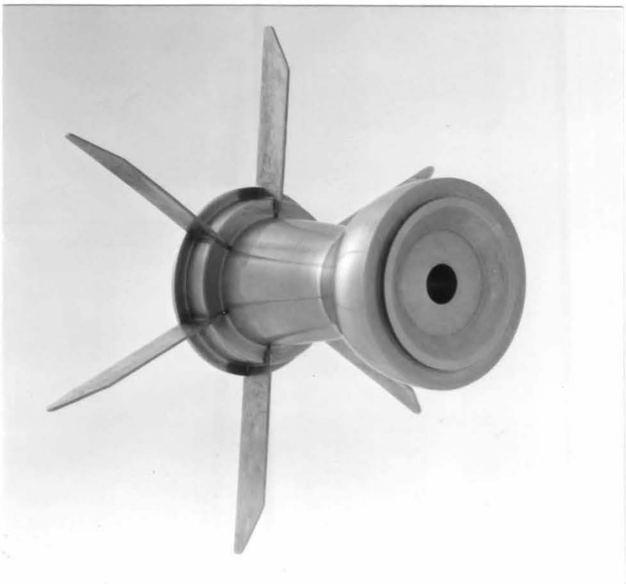


FIGURE 5

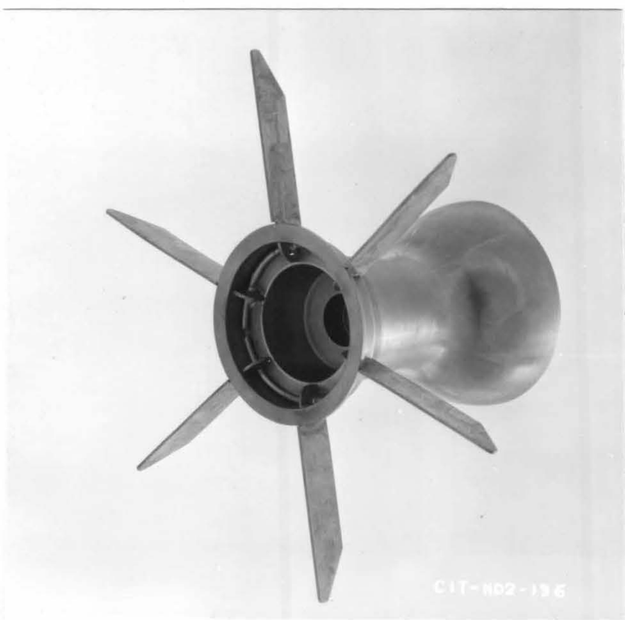


FIGURE 6

CONSTRUCTION DETAILS OF FIN
TAIL FOR 4.5" ROCKET PROJECTILE

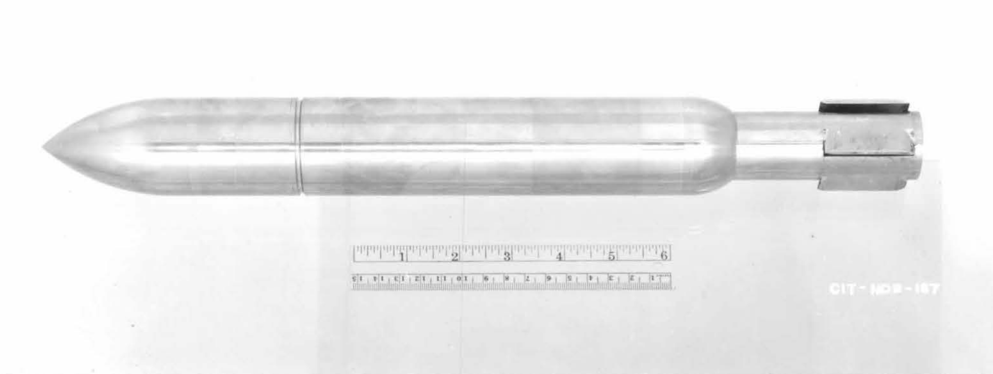


FIGURE 7

FIGURE 8

FIGURE 9

VIEWS OF 4.5" ROCKET PROJECTILE
EQUIPPED WITH SPINNER TUBE – MODEL I

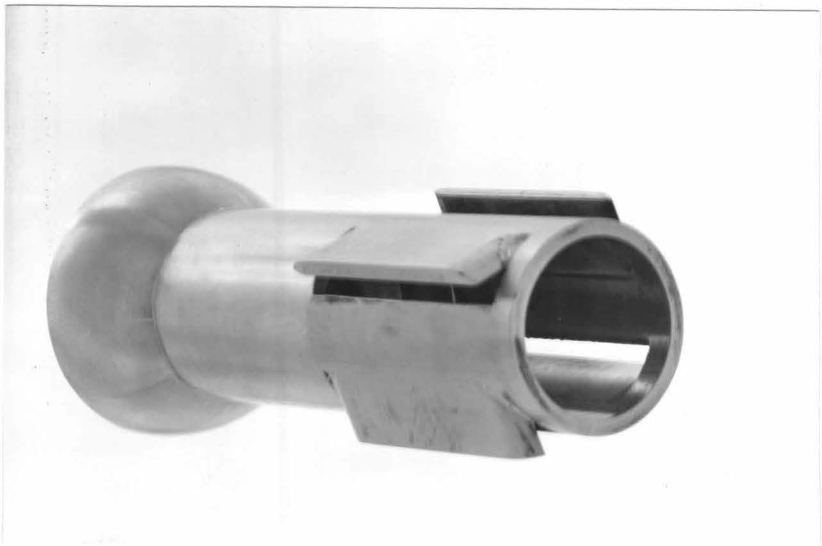


FIGURE 10

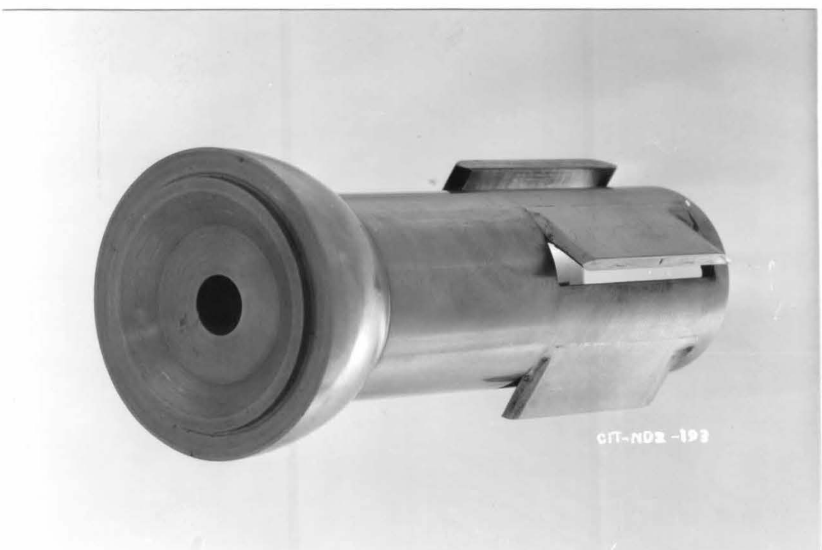
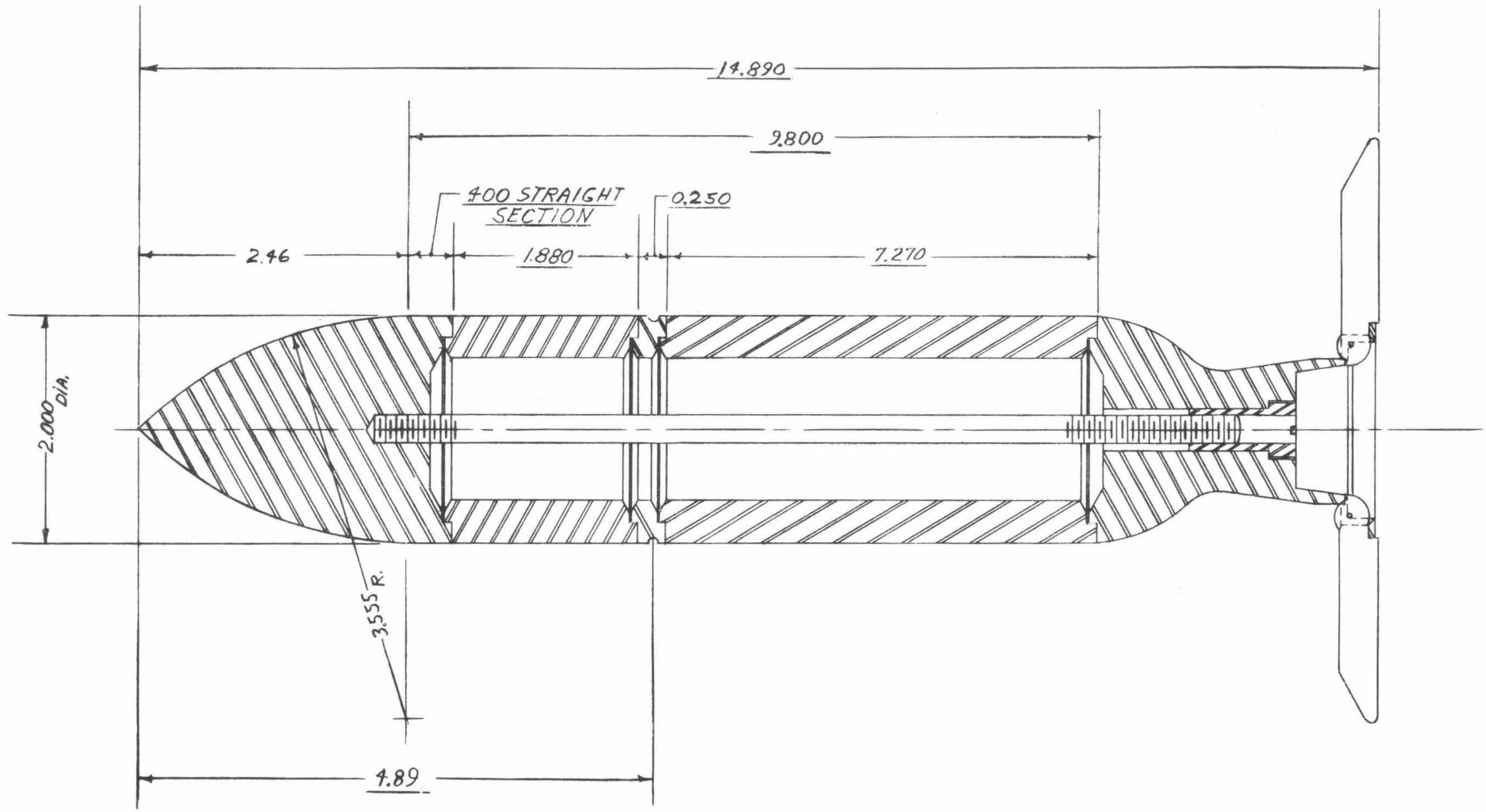


FIGURE 11

DETAILS OF CONSTRUCTION
OF SPINNER TUBE – MODEL I



HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

MODEL ASSEMBLY
ND-12 SERIES
4.5" ROCKET PROJECTILE

DR ODT 12-28-42	SCALE ~ NONE
CH HB	ND-186-14 -U
AP J W Daily	

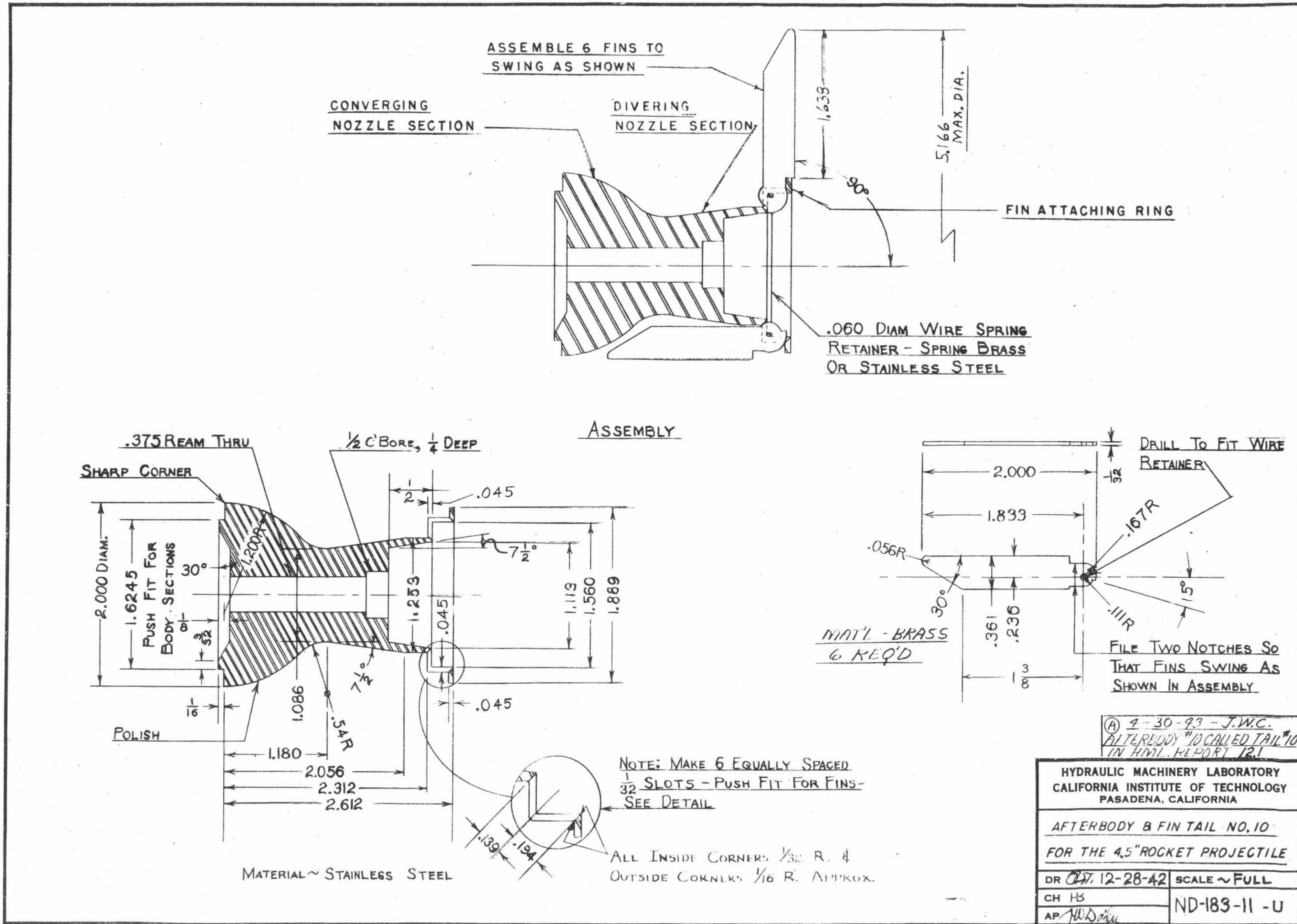

ASSEMBLE 6 FINS TO SWING AS SHOWN
CONVERGING NOZZLE SECTION
DIVERING NOZZLE SECTION
1.638
5.166 MAX. DIA.
90°
FIN ATTACHING RING
.060 DIAM WIRE SPRING RETAINER - SPRING BRASS OR STAINLESS STEEL
ASSEMBLY
.375 REAM THRU
1/2 C'BORE, 1/4 DEEP
SHARP CORNER
1/2
.045
2.000 DIAM.
1.6245 PUSH FIT FOR BODY SECTIONS
30°
1.200R
7 1/2°
1.253
.045
1.113
1.560
1.889
1/16
3/32
1/16
POLISH
1.086
.54R
7 1/2°
.045
1.180
2.056
2.312
2.612
NOTE: MAKE 6 EQUALLY SPACED 1/32 SLOTS - PUSH FIT FOR FINS - SEE DETAIL
.139
.194
ALL INSIDE CORNERS 1/32 R. & OUTSIDE CORNERS 1/16 R. APPROX.
MATERIAL ~ STAINLESS STEEL
DRILL TO FIT WIRE RETAINER
2.000
1/32
1.833
.167R
.056R
15°
30°
.111R
MAT'L - BRASS
6 REQ'D
.361
.236
1 3/8
FILE TWO NOTCHES SO THAT FINS SWING AS SHOWN IN ASSEMBLY
(A) 4-30-43 - J.W.C. AFTERBODY #10 CALLED TAIL #10 IN HML REPORT 121
HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
AFTERBODY & FIN TAIL NO. 10
FOR THE 4.5" ROCKET PROJECTILE
DR 12-28-42
SCALE ~ FULL
CH HB
AP
ND-183-11 -U

FIG. 21

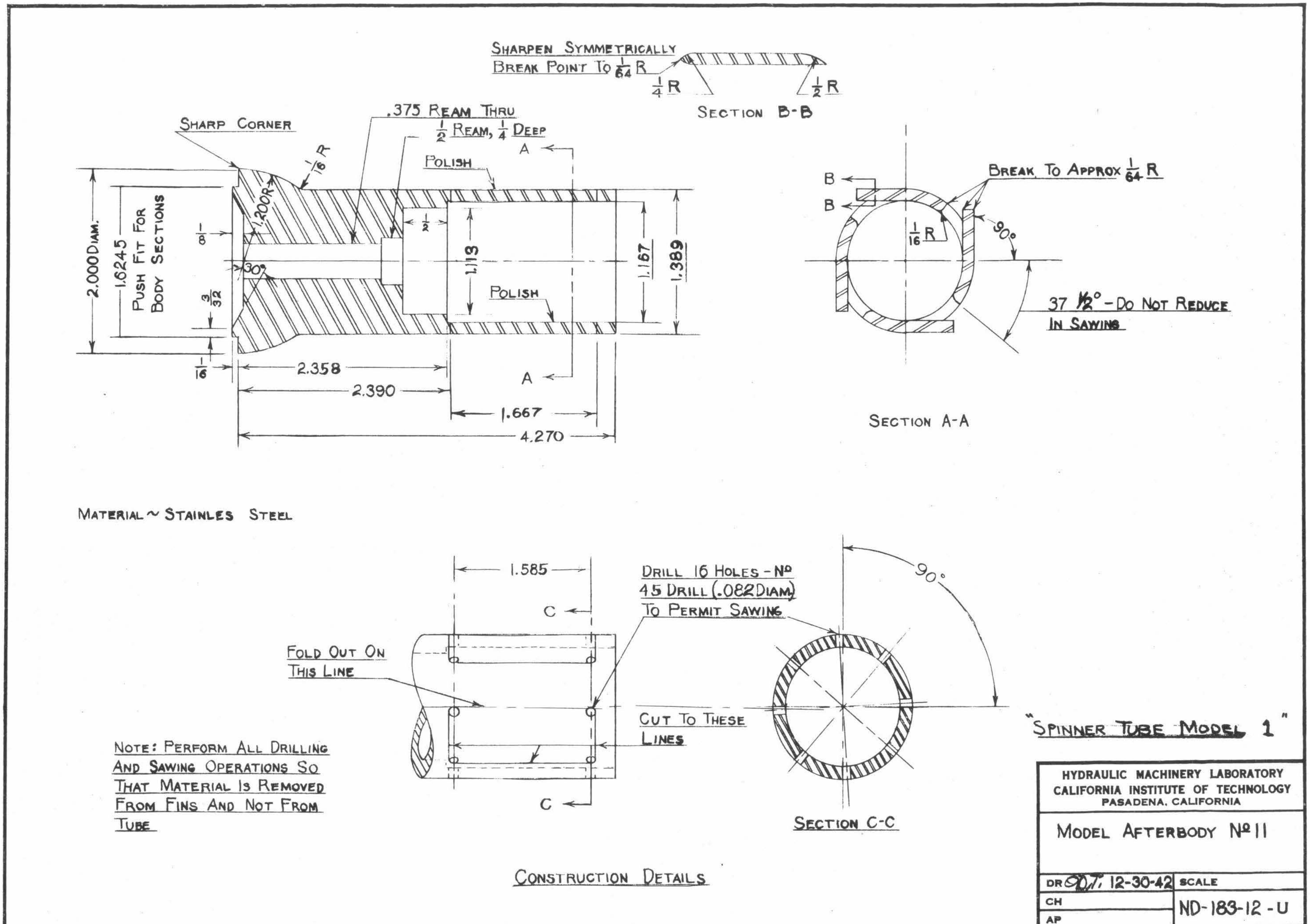

SHARPEN SYMMETRICALLY
BREAK POINT TO 1/64 R
1/4 R
1/2 R
SECTION B-B
.375 REAM THRU
1/2 REAM, 1/4 DEEP
SHARP CORNER
1/16 R
A
POLISH
2.000 DIAM.
1.6245
PUSH FIT FOR BODY SECTIONS
1.200R
1/8
30°
3/32
1/16
1/2
1.113
POLISH
1.167
1.389
2.358
2.390
1.667
4.270
A
B
B
BREAK TO APPROX 1/64 R
1/16 R
90°
37 1/2° - DO NOT REDUCE IN SAWING
SECTION A-A
MATERIAL ~ STAINLES STEEL
1.585
C
DRILL 16 HOLES - Nº 45 DRILL (.082 DIAM.) TO PERMIT SAWING
90°
FOLD OUT ON THIS LINE
CUT TO THESE LINES
C
SECTION C-C
NOTE: PERFORM ALL DRILLING AND SAWING OPERATIONS SO THAT MATERIAL IS REMOVED FROM FINS AND NOT FROM TUBE
"SPINNER TUBE MODEL 1"
HYDRAULIC MACHINERY LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
MODEL AFTERBODY Nº 11
CONSTRUCTION DETAILS
DR 12-30-42
SCALE
CH
AP
ND-183-12-U

FIG 14

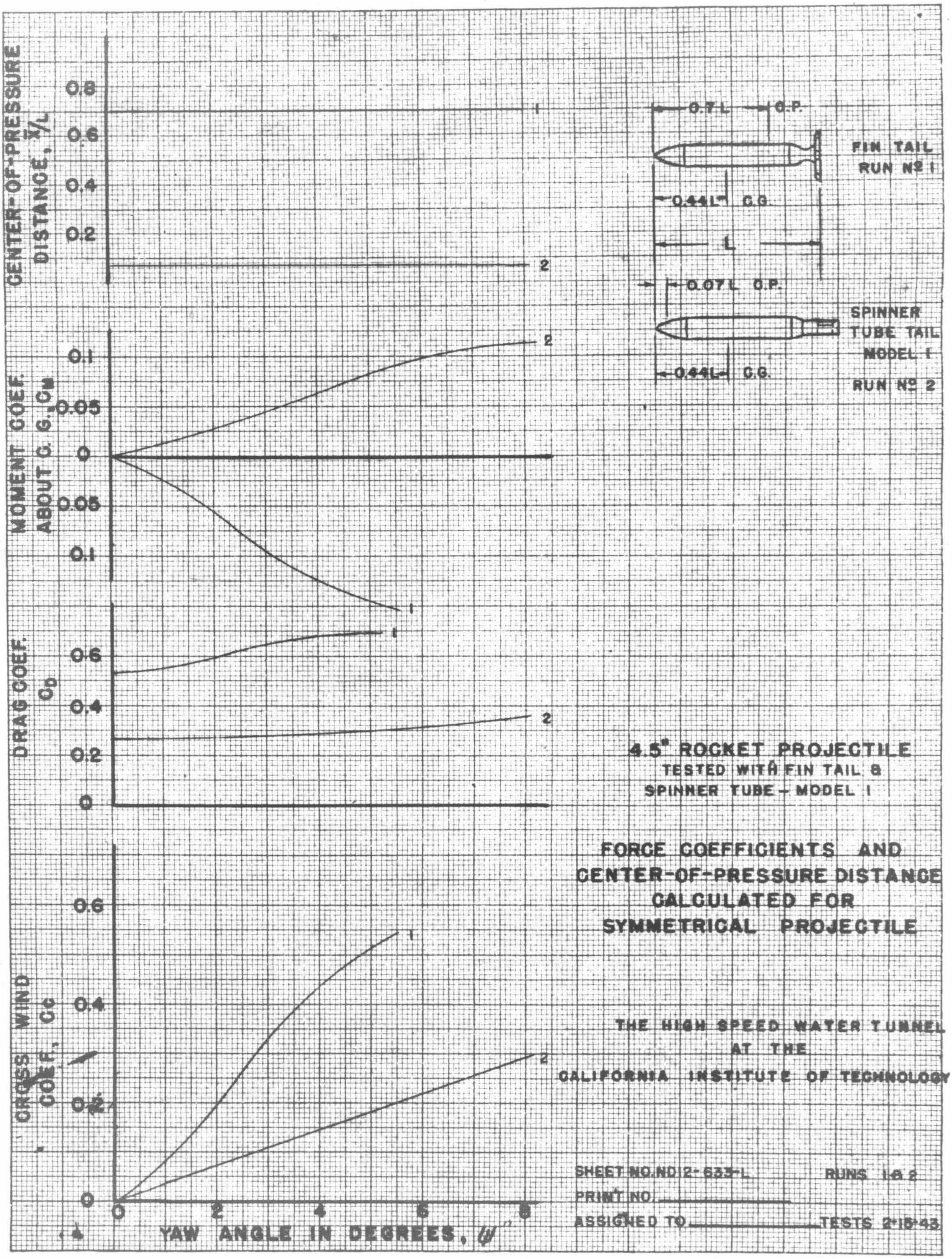

CENTER-OF-PRESSURE DISTANCE, X/L
0.8
0.6
0.4
0.2
MOMENT COEF. ABOUT C. G., C_M
0.1
0.05
0
0.05
0.1
DRAG COEF. C_D
0.6
0.4
0.2
0
CROSS WIND COEF., C_C
0.6
0.4
0.2
0
0
2
4
6
8
YAW ANGLE IN DEGREES, ψ
1
2
0.7L
C.P.
0.44L
C.G.
L
0.07L
C.P.
0.44L
C.G.
FIN TAIL
RUN Nº 1
SPINNER
TUBE TAIL
MODEL 1
RUN Nº 2
4.5" ROCKET PROJECTILE
TESTED WITH FIN TAIL &
SPINNER TUBE - MODEL 1
FORCE COEFFICIENTS AND
CENTER-OF-PRESSURE DISTANCE
CALCULATED FOR
SYMMETRICAL PROJECTILE
THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
SHEET NO. ND12-633-L
RUNS 1 & 2
PRINT NO.
ASSIGNED TO
TESTS 2-15-43

FIG. 15

5. TEST RESULTS.

Figure 15 shows the coefficients and center-of-pressure distances as functions of the yaw angle for the 4.5" rocket projectile tested with regular collapsible fin tail and with the Spinner Tube, Model I. The curves marked "1" are for the model with the fin tail and those marked "2" are for the model with the Spinner Tube, Model I. The center-of-pressure distances for both tests are expressed as fractions of the same length (L=14.89" for the model). The values shown were obtained by fairing and averaging the actual test data to eliminate the irregularities caused by asymmetry built into the projectile. [2] It is believed that these curves closely approximate the performance to be obtained from a perfectly symmetrical rocket. This treatment was used because the performance for the non-symmetrical rocket is different for every plane of yaw so that a very complicated motion in flight must be expected. Such behavior will certainly introduce extra dispersion or scatter when the rocket is fired. While the complicated behavior predicted from tests of an asymmetrical rocket is probably typical of many projectiles it cannot be said with assurity that it is representative of a large group of projectiles without examination of the limits of asymmetry to be encountered. Furthermore, the non-symmetrical effects tend to mask the influence of changes in design so that proper interpretation of the actual test data is difficult. For these reasons it seems more valuable to study the symmetrical case.

The center-of-pressure distance, $\bar{x}/L$, for the projectile with the fin tail is 0.70. Since the C.G. is located at approximately 0.44 L the projectile is statically stable. This fact is also indicated by the negative slope of the moment coefficient curve. The large margin for stability as represented by the distance between the C.P. and the C.G. is illustrated graphically by the small drawing on the curve sheet.

When the fin tail is replaced by the Spinner Tube, Model I, the center of pressure falls at 0.07L. Assuming the same C.G. by neglecting the small effect of the difference in weight between the spinner tube and the fin tail, the relative locations of the C.P. and C.G. are shown graphically by the small drawing on the curve sheet. It is clear that the projectile with the spinner tail is statically unstable. This agrees qualitatively with the results of tests on streamline shapes without tails. Tests of a 6 caliber cylindrical body with a hemispherical nose and a square end [3] gave values of $\bar{x}/L$ varying from approximately 0.27 at $\psi = 0^\circ$ to 0.20 at $\psi = 10^\circ$. Tests of shorter bodies also show only a small effect of length when the caliber is changed from 4 to 6. It is thought, therefore, that the results can be compared with the present tests on this rocket projectile which has an overall length of approximately 8 calibers. It is concluded, therefore, that $\bar{x}/L$ is less for this rocket with the spinner tube than for a conventional rifle projectile with a square end. Consequently, it is expected that if the rocket projectile with spinner tube is to attain the same stability as a conventional bullet of similar proportions it will have to be spun faster than the bullet. (4)

In Table I are shown the measured drag coefficient and the calculated skin friction drag coefficient for the two projectiles. The difference between C_D and the skin friction coefficient gives the form or pressure drag coefficient.

TABLE I.

	Measured Values	Calculated Values: Skin Friction Coefficient	Calculated Values: Form Drag Coefficient (by subtraction)
Regular Fin Tail	0.53	0.10	0.43
Spinner Tube, Model I.	0.27	0.10	0.17

The projectile with the regular fin tail has a large drag with $C_D = 0.53$. As the table shows, the larger portion of this is form drag. The detail photographs of Figures 3 and 6 show that the fin attaching ring on the motor nozzle offers a serious obstruction to the flow as it sweeps past the afterbody of the projectile. If the drag coefficient of the fins and the attaching ring is 0.71 it will account for all of the form drag of the projectile. Actually the fins and ring cannot account for all of the form drag since some of it must be due to the afterbody and the nozzle. However, since the C_D of 0.71 is a reasonable value for bluff forms such as the fin attaching ring, the indication is that the fins and the ring are causing most of the form drag.

The drag coefficient with the spinner tube is 0.27 at $\psi = 0^\circ$ compared to 0.53 for the projectile with the fin tail. The skin friction must be approximately the same for both versions of the rocket so the reduction in drag is caused primarily by reducing the form or pressure drag contribution. As Table I shows the estimated form drag coefficient is only 0.17 for the rocket with spinner tube as against 0.43 with the fin tail.

6. SUMMARY.

The test results show that the static stability of the 4.5" rocket with the fin tail is very good, but that the drag coefficient is high. This large drag is caused by the obstructions offered to the flow by the fins and fin attaching ring of the tail. The drag can be reduced by fairing or streamlining the afterbody and the protruding portions of the tail structure. It is recommended that the details of attaching the fins to the nozzle be reconsidered with this in mind.

The tunnel tests of the projectile with the Spinner Tube, Model I, showed it to be statically unstable. These tests of course do not include the effects of spinning which contribute to the stability in free flight. Furthermore, the degree of instability is so large, that it is anticipated that for satisfactory behavior more spin will be required for this rocket than for a normal rifle bullet of the same proportions. The drag of the rocket with the spinner tube is less than for the fin tail. This is caused by a reduction in the form drag.

REFERENCES:

(1) For complete description see "The High Speed Water Tunnel at the California Institute of Technology", by R.T.Knapp, V.A Vanoni, and J.W.Daily, HML Rep. No. ND-1, June 29, 1942.

(2) For a more complete discussion of the effects of asymmetry and the method of approximating the performance curves for symmetrical projectiles, see "Memorandum on Water Tunnel Tests of a 2.37" Rocket Projectile with Collapsible Type Tails", by R.T.Knapp, HML Rep. No. ND-11.1, January 20, 1943.

(3) "Memorandum on Water Tunnel Tests of 2" Diameter Projectiles with Hemispherical Noses and Square Ends", by R.T.Knapp, HML Rep. No. ND-10, November 10, 1942.

(4) For a discussion of the stability of projectiles with spin see "Elements of Ordance", by T.J.Hayes, Chapter X, Wiley, 1938.